Vegetation Recovery After Spraying with an Eco-friendly Soap-based Firefighting Agent in Model Peatlands in Indonesia

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Abstract. Peat fires are recognized as a significant driver of global warming and environmental degradation. These fires release substantial greenhouse gases and cause serious issues such as smoke pollution, health risks, and ecological damage. Although firefighting agents are increasingly used as an effective countermeasure, their ecotoxicological effects require careful assessment. In this study, we evaluated peatland vegetation recovery after model fires extinguished with a soap-based firefighting agent in Palangka Raya, Indonesia. Peatland biotopes containing seeds and root systems of wild plants native to the peatland were subjected to combustion, followed by firefighting operations using either water or the soap-based agent. Vegetation recovery was monitored for 1 year. Direct site observations confirmed the growth of young *Acacia mangium*, a species native to Kalimantan forests, in all post-combustion biotope boxes, regardless of treatment. This finding indicates that the tested soap-based agent did not inhibit the regeneration of vegetation.

Keywords: Peat fire, Tropical vegetation, *Acacia mangium*, Soap-based firefighting agent.

1 Introduction

Peat is a soil type formed in tropical and subarctic regions through the accumulation of dead vegetation and other plant material in an undecomposed state. Indonesia possesses vast peat deposits, accounting for roughly half of the world's total (Strack et al., 2008). These soils have extremely high carbon content, and once ignited, can burn for prolonged periods. Peat fires (Shiraishi & Hirata, 2021) and wildfires (Gatti et al., 2021) have been reported to accelerate global warming and environmental degradation; in

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turn, further global warming is expected to increase the frequency of both wildfires and peatland fires (Mansoor et al., 2002). Indonesia regularly experiences peat fires, with the most severe event to date occurring in 2015, when approximately 4.6 Mha of peatland forest burned, releasing an estimated 0.89 Gt of carbon dioxide equivalents (Lohberger et al., 2018). Such fires also cause smoke-related hazards to aviation, health problems for local communities, and significant ecological damage, with effects that can extend to neighboring countries (Subekti et al., 2017). Prevention of and firefighting against peat fires are therefore critical issues of global concern.

Peat fire management includes early detection, preventative measures, and active suppression. Water is the most widely used fire suppressant; however, peat soils are highly water-repellent, and water's high surface tension limits its penetration, making suppression particularly challenging. It is well recognized that additions of surfactant-based agent effectively lower surface tension, improving infiltration into combustible materials and increasing suppression efficiency (Santoso et al., 2021; Zhdanova et al., 2023). However, synthetic surfactant-based agents raise concerns regarding environmental toxicity (Kawano et al., 2014).

To reduce such impacts, soap-based firefighting agents (SFAs) have been developed (Mizuki et al., 2007; Kawahara et al., 2016). When the SFAs reach the natural environmental waters rich in minerals, the soap components readily react with calcium and other ions to form so-called soap scum, which no longer possesses surfactant properties and thus is effectively nontoxic. Previous studies have reported no adverse effects on rice germination or growth (Kawano et al., 2007 a) and low toxicity to aquatic organisms (Goto et al., 2007; Kawano et al., 2007 b). In addition, SFAs are highly biodegradable (Mizuki et al., 2010), making long-term environmental persistence unlikely.

SFAs can be efficient firefighting tools against Indonesian peat fires, since they facilitate fire extinction in less time and with minimal quantities of water (Kanyama et al., 2025 a). However, assessing their environmental performance is equally important. A key question is whether vegetation can regenerate following firefighting operations with SFAs and whether pre-fire ecological conditions can be restored.

Accordingly, in this study, we investigated whether an SFA inhibits vegetation recovery after peat fires. We evaluated the restoration of peatland vegetation following firefighting operations in the model peat fire experiments using water or an SFA. The study was conducted in a series of small-scale model peatland biotopes located within the experimental forest of the University of Palangka Raya, Indonesia.

2 Materials and Methods

2.1 Preparation of SFA

The SFA in this study consisted of two soap components (potassium laurate and potassium oleate), a chelating agent sodium aspartic acid diacetate (ASDA), and diluents, namely, water, propylene glycol (PG), and methylpentanediol (MPD). Purified water and 18.3 wt.% ASDA were mixed at 50°C with stirring, followed by sequential addition of 12.5 wt.% PG, 5.3 wt.% MPD, 3.4 wt.% potassium hydroxide, 5.7 wt.% lauric acid, and 7.0 wt.% oleic acid.

2.2 Site and Biotope Box Test Protocol

All experiments were conducted in an experimental forest on the campus of the University of Palangka Raya, Palangka Raya (Central Kalimantan Province, Kalimantan Island, Indonesia). For the biotope experiments, ground vegetation in designated peatland forest areas was mechanically removed, after which peat soil blocks (0.3 m square) were collected and air-dried in biotope boxes (1.5 m × 1.5 m × 0.3 m wooden frames). Combustion and firefighting experiments using these boxes were performed during the dry season. For burning, paraffin-based fire igniters and dried wooden rods of *Acacia mangium* were placed at the center of each box, and the peat soil was ignited. For firefighting, either water alone or an SFA solution (1 vol.%), prepared with local groundwater, was applied to the burning peat soil in the boxes. Fire suppression was performed manually with a backpack-type water tank (Jet Shooter EV, Ashimori Industry Co., Ltd., Osaka, Japan). Spraying continued until the peat surface temperature fell below 50°C, as measured using a thermal imaging camera (E6xt, FLIR Systems Inc., Wilsonville, OR, USA). Vegetation surveys were then conducted by periodically observing the biotope boxes after firefighting.

3 Results and Discussion

In the campus forest where the peat soils were collected, natural vegetation consisting of ferns, grasses, shrubs, and trees has been observed. Vegetation recovery after a damaging fire likely involves the emergence of ferns, grasses, and shrubs before tree species (Ough, 2001). Observations of the biotope boxes indicate that vegetation recovery may begin with these species, followed by trees.

Herein, we observed that the regeneration of various plants, including *A. mangium*, had begun in the boxes about 1 month after the firefighting experiments. Our environmental assessment focused on the distinctive ecological traits of this species.

A. mangium is recognized as a key species for reforestation programs in tropical wastelands (Thomas, 2014), as it naturally aids in the recovery of vegetation following wildfires. For example, the seeds of *A. mangium* can remain dormant in the soil for many years and germinate only after exposure to heat above 100°C (Saharjo & Watanabe, 1997).

No germination occurred in boxes that were completely burned without firefighting operations (Table 1, a), likely because complete combustion destroyed seed viability. Similarly, seeds not exposed to heat (Table 1, b) failed to germinate; when the aboveground vegetation was merely mechanically removed, germination of *A. mangium* did not occur due to the absence of heat stress.

In contrast, in heat-stressed boxes sprayed with either water or the SFA solution, *A. mangium* germinated and grew to comparable levels (Table 1, c–f). Taken together, these results indicate that the SFA used in this study did not inhibit the recovery or restoration of peatland forest vegetation.

Table 1. Effects of firefighting on revegetation above the peat soils (biotope box test results).

	Extent of combustion	Firefighting treatment	Revegetation (Tree score)		Box observed
			6th Mo.	12th Mo.	
a	++	-	-	-	2A
b	-	-	-	-	4B
c	+	W	+	+	1A
d	++	W	++	+++	3C
e	+	SFA	++	+++	1B
f	++	SFA	++	+++	3B

Extent of combustion: The control plot without fire application was scored negative (-), while partial and full combustion were scored (+) and (++), respectively. **Firefighting treatments:** The control plot without any firefighting operation was scored negative (-), while the application of water and SFA were marked as (W) and (SFA), respectively. **Revegetation:** The tree score represents the evaluation of the early recovery phase of the tree species (here, *A. mangium*). The negative symbol (-) represents the absence of *A. mangium*. The symbols (+), (++), and (+++) represent the emergence of a single seedling, multiple seedlings, and multiple seedlings taller than 1.4 m (breast height), respectively.

As shown in Figure 1, emerging young plants of *A. mangium* were observed in boxes sprayed with either water or the SFA solution. The plants of *A. mangium* in both boxes grew to a height of approximately 1 m within 6 months (images modified from Kanyama et al., 2025 b).

Fig. 1. *A. mangium* in biotope boxes 6 months after firefighting.

Figure 2 presents a series of aerial photographs of the experimental site, taken over a 1-year period beginning immediately after the firefighting activity. Initially, no plants were present in the boxes; however, vegetation gradually recovered over time, and by the 12th month, most *A. mangium* individuals had grown to heights exceeding 1.4 m. The temporal sequence of vegetation restoration shown in Figure 2 indicates that SFAs did not inhibit either the germination or growth of *A. mangium*, nor did adversely affect the recovery or growth of other plant species.

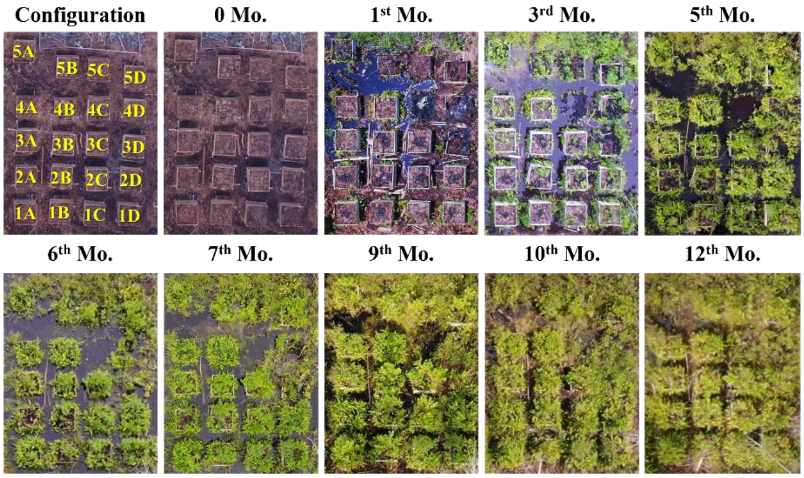

Fig. 2. Restoration of vegetation in biotope boxes over a 1-year period.

In addition to their favorable environmental performance, the high firefighting efficiency of the SFA used in this study against model peat fires was evaluated (Kanyama et al., 2025 a). Compared with water alone, both the volume of water required and the time needed for extinguishing were substantially reduced in the model peat fires within the biotope boxes, as shown in Table 2 (data modified from Kanyama et al., 2025 a). The SFA required approximately one-quarter of the water volume and one-third of the extinguishing time, highlighting its strong suppression capability.

Table 2. Water volume and time required for peat firefighting

	Water	SFA
Water volume required per unit area	16.0 L/m^2	3.8 L/m^2
Time required	29 min	11 min

In this study, we demonstrated that an SFA does not inhibit the germination of heat-stimulated seeds of *A. mangium* in the biotope boxes. As illustrated in Figure 3, complete combustion damaged the seeds and prevented germination, whereas moderate heat stress combined with firefighting operations markedly promoted the germination of *A. mangium* a process essential for regeneration of the peat forest vegetation. Although most firefighting agents are reported to have environmental impacts, particularly ecotoxicity to living organisms, SFAs appeared environmentally benign, as demonstrated here with *A. mangium*. Detailed results from large-scale field tests of environmental performance are planned for publication in the near future. Furthermore, future studies should examine the effects of SFAs on other native plant species in peatland ecosystems to provide a more comprehensive assessment of their environmental compatibility.

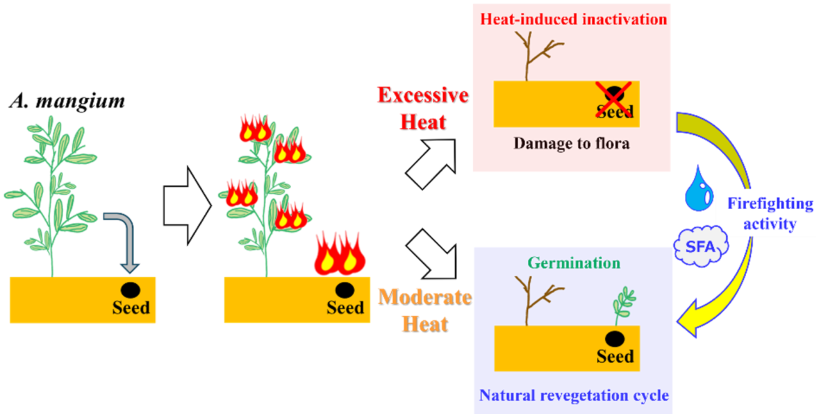

Fig. 3. Fate of *Acacia* seeds after peat fires with and without firefighting operations.

4 Conclusion

Results from the biotope box experiments confirmed that the SFA used in this study did not inhibit the heat-induced germination or early growth of *A. mangium*, a key indicator species in tropical peat forest vegetation recovery following fires. Overall, post-fire vegetation recovery was comparable in boxes treated with an SFA and those treated with water alone. As SFAs have gained increasing attention in recent years for combating peat fires, the present findings supporting their ecological safety may help promote broader public acceptance.

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